

The Effects of Magnetic Storm Phases on F-layer Irregularities from Auroral to Equatorial Latitudes

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1 October 2000 through 30 September 2001

Award Number: N00014-89-J-1754

<http://www.bu.edu/csp/>

LONG TERM GOALS

Since ionospheric irregularities under certain geophysical conditions deteriorate the accuracy and capability of ground, airborne, and satellite navigation and communication systems, the long term goal was to add to forecasting capability of equatorial and high latitude irregularities. Forecasting allows use of systems less sensitive to ionospheric conditions. In addition, field users of systems will know that natural conditions rather than equipment deterioration are creating problems. Initially the sensors and data in our study were amplitude and phase scintillation on radio beacon signals; we now have other sensors.

OBJECTIVES

The grant objective was to study and understand the morphology and physics of irregularities at high and equatorial latitudes as a means of attacking the forecasting problem. The study started with data that were available from earlier field programs which had not been analyzed. Our present approach is to forecast the development of equatorial irregularities by correlating them with high latitude phenomena. We are particularly interested in the equatorial anomaly region where fades of 20 dB and more on GPS signals can be frequently found in years of high solar flux. These include cities such as Bogota, Santiago, and Cairo as well as portions of the Middle East. The primary data are observations of the phase fluctuations of the Global Positioning System's satellites at all latitudes. We correlate these data sets with DMSP observations, with high latitude magnetograms, and with depletions of electron density as observed by all-sky optics.

APPROACH

In a series of papers we have documented the effect of magnetic storms on GPS phase fluctuations at auroral latitudes. The temporal development of phase fluctuations is a function of the Universal Time development and intensity of the storm and the local magnetic time at a given site. The effects of individual storms can be dominated by storm time or by local magnetic time. In the auroral region development of irregularities expands predominantly equatorwards. The individual storm expands

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 2001		2. REPORT TYPE		3. DATES COVERED 00-00-2001 to 00-00-2001	
4. TITLE AND SUBTITLE The Effects of Magnetic Storm Phases on F-layer Irregularities from Auroral to Equatorial Latitudes				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Boston University,,Center for Space Physics,,Boston,,MA, 02215				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

most dramatically at certain longitudes moving into what were sub-auroral latitudes near magnetic midnight but this movement is controlled to a large extent by the storm dynamics. In addition to producing intense phase fluctuations at auroral latitudes, there are at least SOME magnetic storms which produce relatively obvious effects at equatorial latitudes. A storm may penetrate the rapid set-up of shielding mechanisms at high latitudes and affect the equatorial region.

WORK COMPLETED

Magnetic Storm Studies

We have completed our study of the correlation of local auroral magnetograms at stations such as Fairbanks and phase fluctuations on GPS receivers. Both amplitude and phase are affected during magnetic activity in this region. Our best “nowcasting tool” is to watch local magnetograms to warn of reception problems for both GPS and other satellites such as Fleetsatcom.

At this stage we are attempting to isolate magnetic storms which have effects at equatorial latitudes. We completed our study of both equatorial and high latitude irregularities using ground and satellite ionospheric data collected for the magnetic storm of May 1-5, 1998. We now have the use of the DMSP electron density data with the assistance of Peter Sultan of the Air Force Research Laboratory. We used auroral magnetograms, DMSP observations of equatorial depletions of ionospheric electron density, and GPS phase fluctuation observations from equatorial and high latitude stations to examine the effect of the May 1998 magnetic storm on the development of irregularities. The new version of this study has been completed and includes DMSP data; it has been submitted to Radio Science for possible publication. It adds the possibility that some magnetic storms have effects in both the post sunset and post midnight periods.

One example of the comparison of data sets in our new studies that is relevant is that from the storm of May 15, 1997 as shown in Figure 1. Equatorial irregularities develop primarily after sunset when the F layer rises. After the F layer velocity of rising decreases, radar studies show that F layer irregularities develop. However, irregularities also develop after midnight. In Figure 1 we show the UT day of May 15 with auroral contours of phase fluctuations at Flin Flon, Canada, and with Guam phase fluctuations in the post midnight period. DMSP observations of the longitude region encompassed by Guam (at 145° East) show the variations in electron density near the magnetic equator. In the post-midnight time period Guam showed phase fluctuations developed by the electric field variations during this magnetic storm. These electric field changes affected the longitudes shown. The effect on phase fluctuations on the Guam records can be readily seen in the post-midnight time period. DMSP ion depletion data from the Air Force Research Laboratory shows the confinement of irregularities to perhaps 55 degrees of longitude. The time sequence of the records also shows the delay in the strong effects of the magnetic storm activity which peaked at 12 UT.

We now have on hand reduced data and DMSP observations for magnetic storms of various magnitudes during low and high solar flux years; the approach is to organize these into a coherent picture of the relationship of magnetic activity to the development of equatorial irregularities.

DURIP Imaging Study

The Defense University Research Instrumentation Program (DURIP) award to Boston University had as its goal the creation of a versatile imaging capability for targets in the terrestrial or celestial domain, as viewed through a turbulent atmosphere. The technique, called high definition imaging (HDI) uses high speed (>60 frames/sec) digital recording of images taken simultaneously in broadband (“white light”) and in narrow spectral ranges. The white light images are used to assess seeing and to identify the rare subset of images suitable for shift-and-add integration of the spectral images. The spectral component utilizes new Echelle spectrograph and image slicer designs developed in-house at Boston University. To test the white light component of the system, and to evaluate several image processing methods of “perfect seeing” identification, an analysis was conducted of data taken at low elevation angles of the planet Mercury. The results gave the best-to-date image taken with a groundbased telescope of a portion of Mercury’s surface that was not photographed by NASA’s Mariner 10 program in 1974-75. Results of this work have been published (Baumgardner et al., 2000) as shown in our last ONR report.

IMPACT/APPLICATIONS

Over the period of the contract, we have initiated new approaches to the global morphology of irregularities of importance for communication and navigation systems. Phase fluctuations affect GPS in that difficulties with simple equipment can result from amplitude scintillations and difficulties in accuracy can result from phase scintillations. The areas where the problems are important are the auroral region and the equatorial region. We have shown how the auroral region for these effects can extend to middle latitudes of the U.S. We have shown how Fairbanks in the auroral oval is subject to magnetic storm effects. In the equatorial region we are probing the effect of magnetic storms on equatorial irregularities. We have shown earlier that localized irregularities are responsible for the magnetic equator scintillations observed at such places as Guam, Kwajalein, and along the magnetic equator line in South America. We expect to go from these studies to determine the extent of the magnetic storm effects: i.e., does it contribute to the instability mechanisms even if it fails to produce a plume in the equatorial region?

TRANSITIONS

Our future studies will aid us in sorting out the timing and strength of auroral effects on equatorial irregularity development. We shall continue these studies using both new data for years of high solar flux as well as previously studied storms during the low solar flux years. Conditions may be quite different for the two sets of data and the effect of high latitude magnetic storms on equatorial irregularities may be in part a function of solar flux.

We examine individual storms since statistics used in many studies may be hiding the control of irregularity development during intense magnetic activity; in particular the role of magnetic storm time of maximum activity has not been fully utilized .

RELATED PROJECTS

Cornell University studies in equatorial scintillation observations are being noted. We are also using data from NRL observations to correlate with our ground and satellite measurements.

PUBLICATIONS

A. W. Stephan, M. Colerico, M. Mendillo, B.W. Reinisch, and D. Anderson, "Suppression of equatorial spread F by sporadic E," *J. Geophys. Res.*, 2001, in press

J. Aarons, M. Mendillo, and P. Sultan, "Equatorial longitudinal confinement of ionospheric irregularities during the magnetic storms of May1-5, 1998," submitted to *Radio Science*

MAY 15, 1997

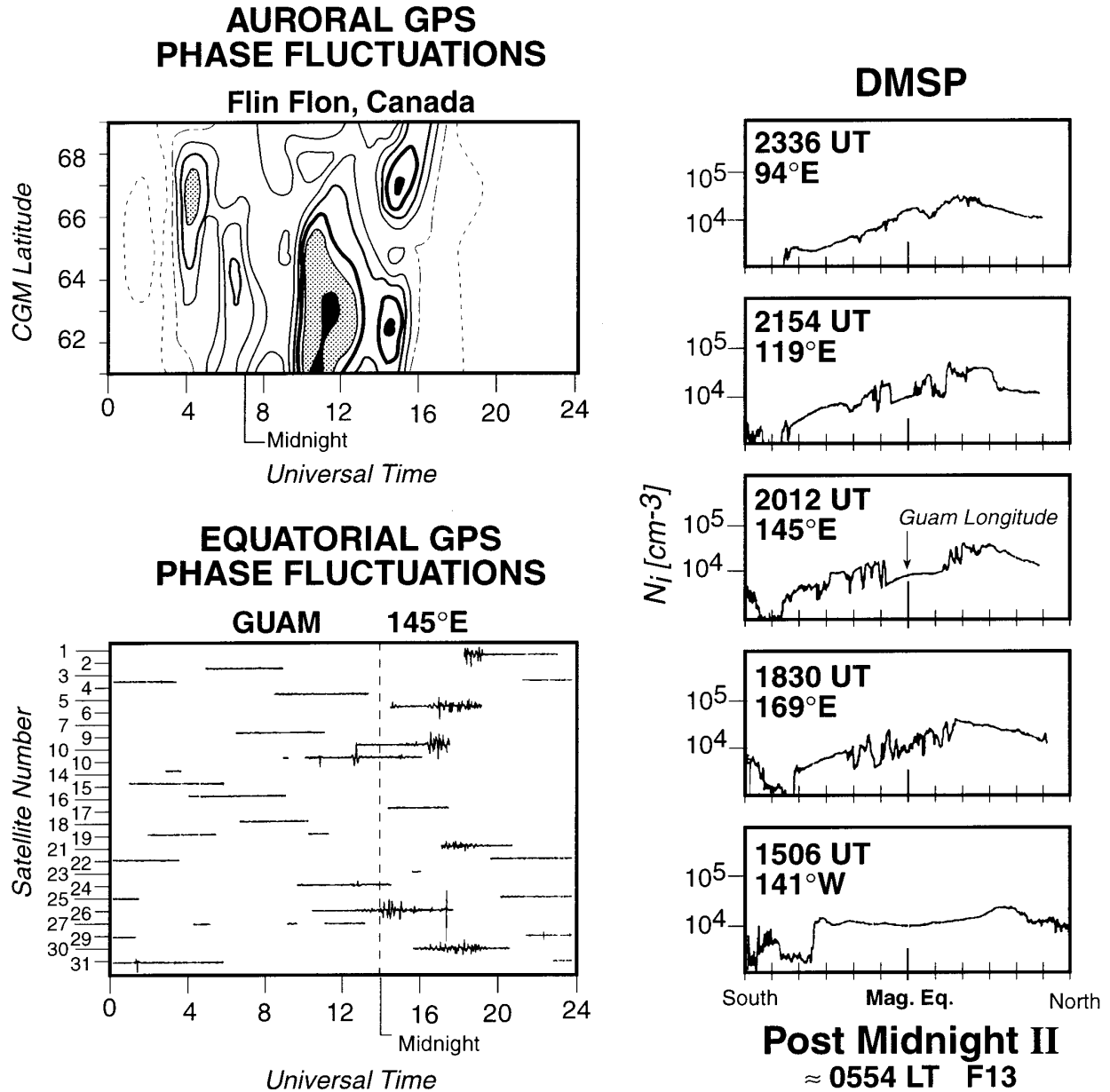


Figure 1. Immediate auroral effects of the May 15, 1997 magnetic storm on GPS phase fluctuations on FlinFlon, Canada records are followed by delayed GPS phase fluctuations on Guam. DMSP data from the Air Force Research Laboratory also shows the equatorial irregularities within a narrow longitude region.